

**REMARKS**

The specification has been amended to place it in proper format for U.S. filing, to add a description of the drawings, to replace line numbers with paragraph numbers, and to correct minor details. The claims have been amended to remove multiple dependent claims.

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Respectfully submitted,



Robert R. Mallinckrodt  
Attorney for Applicant  
Registration No. 26,565

THORPE NORTH & WESTERN, LLP  
Customer No. 20,551  
P.O. Box 1219  
Sandy, Utah 84091-1219  
Telephone: (801) 566-6633

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**SPECIFICATION****BACKGROUND OF THE INVENTION****Technical Field**

[0001] The invention relates to a steam cycle with a steam generator, adapted to have thermal energy transferred to an operating medium and a power engine adapted to convert the thermal energy comprised in the operating medium to mechanical energy. The power engine may also be an expansion machine, wherein the operation medium is expanded producing mechanical energy.

[0002] Normally the steam generator is formed by a heat exchanger which is adapted to have an operation medium flowing therethrough for receiving heat. The operation medium is provided in the form of a fluid. The fluid, for example water or steam, flows through one or more channels which are exposed to a hot gas flow. The hot gas flow can be the hot fumes of a burner, fuel being exothermally combusted therein. Heat is transferred to the fluid when the fluid-carrying channels are exposed to the flow, said fluid being evaporated and overheated. It has a high pressure- and temperature level in the order of several hundred °C when it leaves the steam generator.

[0003] The operation medium is expanded from a higher, first pressure level to a lower, second pressure level in the expansion machine, for example a reciprocating piston machine or a rotational piston machine, producing mechanical energy. Thereby, the piston powers a shaft which in turn serves to power, for example, a generator for electrical energy or for moving a vehicle. The expanded fluid is cooled in a condenser and liquefied and then re-fed to the fluid cycle by means of a pump. The efficiency of the assembly is better for higher pressure- and temperature differences.

[0004] For the present purposes an expansion machine shall be any power engine operating with a gaseous or vaporized operating medium with a phase change. They must be distinguished from power engines with internal combustion, as for example a two-stroke engine, where fuel is combusted inside the power engine. Water steam is particularly suitable as an operating medium, which is expanded producing mechanical energy. The combustion is effected outside the power engine to evaporate the water. A downstream condenser assembly serves to liquefy the expanded operating medium. Typical temperatures of the working medium are in the range of 550°C for the high-energy state of the steam and 100°C for the condenser temperature.

#### **Prior State of the Art**

[0005] Such a steam cycle is known, for example, from the DE 10226445 C1 or DE 10229250.7, {the latter not being pre-published}. The above mentioned cycle is described therein. Feed water is used as an operating medium. Water is easy to handle, cheap and has good thermodynamic properties. The water is evaporated in a vaporizer. The steam is expanded in a rotational piston machine producing mechanical energy. After the expansion the steam is condensed in a condenser and fed to a reservoir by means of a pump where it is available for the cycle again. The described engine is used, for example, as an auxiliary power engine in vehicles. It is, therefore, temporarily switched off. Then the entire water comprised in the cycle is condensed. Depending on the outside temperatures the auxiliary power engine is exposed to temperatures below the freezing point of water. This means that the feed water can freeze. Due to the volume expansion of the water ~~at the transition to~~ as it changes into ice at the freezing point, there is the potential danger of freezing ~~damages~~ damage to the assembly. This problem also exists in different applications, as soon as water is exposed to lower temperatures.

[0006] There are many suggestions to avoid the freezing of the assembly. From DE 43 18 480 A1 it is known to remove feed water from an assembly if the temperatures drop. From DE OS 37 44 102 it is known to provide an additional pump to prevent the formation of ice. From DE 101 17 102 A1 it is known to provide an additional combustion to prevent dropping of the temperature. All these suggestions have a complicated construction and require additional energy.

[0007] Furthermore, it is known to use alcohol in the windshield washer system in motor vehicles. Furthermore it is known to add glycols, for example ethylene glycol, propylene glycol, or diethylene glycol to the cooling system of motor vehicles. These additives lower the freezing point of water whereby it remains liquid even at temperatures below 0°C.

[0008] Adding known anti-freezing compounds to feed water in a steam cycle of the above mentioned kind, however, is not easily possible. The feed water in such a cycle reaches very high temperatures. Known anti-freezing compounds are thermally not stable anymore at such temperatures. Alkanes decompose at 330°C to 360°C. Alcohols decompose at about 140°C to 340°C. Esters decompose at 180°C to 320°C. Their use would lead to the decomposition of the anti-freezing compounds and the decomposition products would produce undesired ~~depositions~~ deposits and corrosion. The limitation of the higher operating temperature of the steam cycle produces, on the other side, with a lower efficiency.

[0009] The term organic Rankine-processes (ORC-Processes) denote steam cycles operating with an organic operating medium. These steam cycles operate at low temperatures. Temperatures above 200°C are rarely reached, for example, in geothermal fields. The same applies if the remaining heat from exhaust fumes is used in a combustion process.

[0010] Due to the small maximum temperature difference between steam and condensed medium the efficiency is small when using feed water as an operating medium. Therefore, water is replaced by an organic operating medium in such assemblies. The organic media used in, for example, DE 100 29 732 A1, have a low boiling point in the range of 70°C to 90°C. Compounds from the classes of fluorine carbohydrates or alkanes are known as operating ~~medium~~ mediums. With their use the condensing temperature is lowered and the temperature difference between steam and condensed medium is increased which effects an improved efficiency. The temperature difference and thereby the theoretical efficiency, however, are also smaller than in a cycle which is operated with water.

[0011] From DE 34 20 293 the use of bicyclic carbohydrates as operating fluids is known. These have a similar temperature difference at an altogether increased temperature level.

#### **DisclosureSummary of the invention**

[0012] It is an object of the invention to provide a frostproof steam cycle which operates with high efficiency without additional energy requirement.

[0013] According to the invention this object is achieved in that the operating medium contains at least one heterocyclic compound, especially a heterocyclic aromatic compound. By adding such compounds it is possible to still operate with water and at high temperatures. The freezing point, however, is reduced to such an extent, that the assembly can operate even at temperatures below 0°C. Depending on the desired freezing point there can be added more or less. Preferably, the operating medium is a mixture containing water and heterocyclic aromatic compounds, water being contained in an amount between 5 and 95 percent by weight and the heterocyclic compound in an amount between 5 and 95 percent by weight.

[0014] Contrary to ordinary aromatic compounds, most heterocyclic compounds are easily mixable with water and, therefore, allow higher concentrations of the added substances, also, if required. They have a high thermal stability and long-term life. This means, that they do not decompose at higher temperatures in the vapor phase. Thereby deposits are avoided.

[0015] If compounds are selected which have a boiling point which is in the same order as the boiling point of water, the demixing is avoided in the vaporizer or condenser in the cycle and the lower efficiency related thereto.

[0016] The heterocyclic atom is preferably nitrogen, oxygen or sulfur. In a preferred modification the operating medium contains 2-methyl pyridine, 3-methyl pyridine, pyridine, pyrrole and/or pyridazine as a heterocyclic compound. These have suitable boiling points and they are thermally stable up to very high temperatures. Alternatively, perfluoric carbohydrates with decomposition temperatures between 420°C and 480°C can be used. However, these have a negative impact on the ozone layer of the earth (green house effect) and they are, therefore, not very suitable for non-technical reasons.

[0017] The viscosity of the mixtures is increased with respect to the pure substances by the addition of heterocyclic compounds. The operating medium, therefore, can also serve as a lubricant for the movable parts of the engine, especially the piston and/or bearings. Such a self-lubricant operating medium has the essential advantage that ~~classical~~ the usual lubricants are not necessary. This means, that the change of oil, the cleaning of the operating medium from entrained lubricant droplets or the like are not required anymore.

[0018] The operating medium can also contain one or more polymers which are mixable with water, such as, for example, Polyethylene glycol or terphenyl, a surfactant and/or

contain other organic lubricants. The addition of such compounds can be useful if the self-lubricant effect of the mixture of feed water and heterocyclic compounds is not sufficient.

[0019] Further modifications of the invention are subject matter of the subclaims. An embodiment is described below in greater detail.

### THE DRAWINGS

[0020] In the accompanying drawings, which show the best mode currently contemplated for carrying out the invention:

[0021] Fig. 1 shows a schematic of the steam cycle of a rotational piston engine.

[0022] Fig. 2 is a graph illustrating the freezing point temperature as a function of the portion of 2-methyl pyridine.

### **Detailed Description of the Illustrated Embodiment embodiment**

[0023] The steam cycle 10 of a rotational piston engine 10 is schematically shown in Fig.1. The steam cycle comprises an expansion machine 14 and a flow steam generator 12. The flow steam generator 12 is exposed to the hot fumes of a burner. The cycle also comprises a feed water pump 16, which is provided with a rotary speed control and a condenser 18. An operating medium in the form of feed water or feed water steam with some additives flows in the flow steam generator 12. The operating medium is pressurized at a higher pressure which is generated by the pump 16. The water or water steam is highly overheated, i.e. heated up to a high temperature and a higher pressure level. The inner energy increases. The steam is expanded in a rotary piston engine 14. Thereby the pressure drops to a lower pressure level. With such an expansion mechanical energy is released. The expanded steam is fed to a condenser 18, wherein



it is condensed to make the water available again in the cycle. Thereby thermal Energy  $\Phi_c$  is released, which can be used, for example, for heating purposes. The condensed water is again fed to the pump 16.

[0024] The operating medium is a mixture of 10 % by weight Water, 89 % by weight 2-Methylpyridin and 1 % by weight Polyethylenglycol. This mixture boils at a temperature of about 95°C. It is thermally stable up to a temperature above 400°C. Therefore, it can be operated at large temperature differences between steam and condensed medium, whereby a high efficiency is achieved.

[0025] The operating medium freezes at a temperature below -40°C. The cycle can also be used in assemblies outside which do not continuously operate, such as is the case with motor vehicle engines or auxiliary power engines for motor vehicles.

[0026] In Fig.2 a graph is shown, illustrating the freezing point temperature as a function of the portion of 2-methyl pyridine. It can be seen clearly, that the freezing point above a portion of about 60% by weight considerably decreases. Depending on the expected minimum outside temperature the amount of the added 2-methyl pyridine can be adjusted.

[0027] Whereas the invention is here illustrated and described with reference to embodiments thereof presently contemplated as the best mode of carrying out the invention in actual practice, it is to be understood that various changes may be made in adapting the invention to different embodiments without departing from the broader inventive concepts disclosed herein and comprehended by the claims that follow.